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 Stylesheet Version 1.0

## Cross Reference to Related Applications

This application is a continuation in part of United States patent application 09/239,112, filed January 28, 1999, which claims priority on United States provisional patent application number 60/073077, filed January 30, 1998.

## Background of Invention

[0001] Field of the Invention. The invention relates to vehicle headliners. In one of its aspects, the invention relates to a vehicle headliner. In another of its aspects, the invention relates to a laminate construction for a vehicle headliner that optimizes formability, sound absorbing properties and structural integrity of the vehicle headliner.

[0002] Description of the Related Art. Vehicle headliners on the interior of an automobile are a decorative panel which separates the passenger compartment from the sheet metal forming the roof of the vehicle. The vehicle headliners absorb sounds from within the passenger compartment as well as sounds originating outside the passenger compartment. Soft fibrous materials are typically used this function, but must be stiffened to give the headliners sufficient structural rigidity to avoid sag in service under all types of service conditions. It is further important that the overall thickness of the headliner be relatively small to maximize headroom within the vehicle compartment. In many applications, it is expected that the headliner will be sufficiently strong to support its own weight.

[0003]

Previous commercial headliners have been made with fiberglass batting which

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is impregnated with a thermosetting resin for rigidity. Some of these panels have been relatively brittle and have failed when installed into vehicles. Further, glass fibers can cause handling problems. These headliners are typically not recyclable.

[0004] The required headliner properties of sound absorption, rigidity, and minimum thickness often conflict with each other and compromises must be made to reach optimum properties. Sound absorption is most easily obtained by making the headliner from a low density material that absorbs the sound waves as they enter the headliner and minimizes reflection of the sound waves as would more dense materials. In general, the greater the thickness of the low-density material, the greater the sound absorption but, thicker materials have a greater tendency to sag and adversely affect headroom. Generally, dense materials are used to provide the headliner with the necessary structural strength and rigidity for supporting its own weight and possibly mounting components to the headliner. More dense materials, in general, tend to reflect sound and thus, negatively impact sound absorption.

[0005] Some prior headliners have attempted to resolve the conflict between the sound absorbing and structural rigidity requirements for the headliner by making the headliner from a laminate of various materials, wherein some of the materials provide the structural rigidity and other of the materials provide the sound absorbing properties. One approach is to use a relatively low-density sound absorbing material sandwiched between two layers of reinforcing material. One of the reinforcing material layers has mounted thereto a decorative cover that forms the ceiling of the passenger compartment of the vehicle. An example of this structure, which is known as an I-beam construction, is disclosed in U.S. Patent No. 4,828,910 to Haussling, issued May 9, 1989.

[0006] Most prior I-beam constructions use a thermosetting resin to bind together the various layers of the laminate. The resin is normally sprayed in liquid form on at least one of the abutting surfaces of the various layers. In general, the thermosetting resin negatively impacts the sound absorbing characteristics of the laminate because the resin can fill the interstitial spaces between the fibers in the laminate and thereby increase the reflectance of the sound waves instead of

absorbing the sound waves. Thermosetting resins also make it more difficult if not impossible to recycle the laminate, which is an important characteristic and often a requirement of most components used in contemporary vehicle construction.

[0007] The U.S. Patent to Weinle, 4,840,832, issued June 20, 1989, discloses a headliner construction of a bicomponent fiber wherein the fibers are bonded together at their crossing points. The headliner is said to be so highly deformable and resilient that it can be bent or flexed nearly double to facilitate installation in an automobile side window and subsequently will resiliently recover to its original molded shape. Actual embodiments of these headliners have not had sufficient rigidity to avoid sag when subjected to elevated temperatures normally experienced in vehicles except when the mass and density of the headliners is very high, thereby negatively impacting vehicle fuel efficiency.

[0008] U.S. Patent 6,066,388 to Van Kerrebrouck discloses a non-woven laminate comprising two outer fiber layers and at least one inner fiber layer having a different composition from that of the outer layers. The inner layer contains constructive fibers having a thickness of 3-100 dtex in combination with 20-100% binding fibers. The outer layers comprise constructive fibers having a thickness of 0.5-28 dtex in combination with 40-100% binding fibers. The thickness of the constructive fibers of the outer layers are thinner than the constructive fibers of the inner layer.

## Summary of Invention

[0009] According to the invention, a laminate comprises first and second strengthening outer layers and a core layer between the strengthening layers. Each of the outer layers comprises a batt of nonwoven polymeric fibers. The outer layer provides the predominate flexural rigidity for the laminate and the core layer provides the predominate sound absorption for the laminate. The core layer batt preferably comprises 20-50% fine fibers, preferably with a denier less than 2.7, 10-50% binder fibers and the balance regular fibers with a denier in the range of 4.0-15.0. The thermoplastic fibers can include polyester, polyolefin, and nylon. The polyester fibers preferably include bicomponent fibers, such as a PET sheath-

core bicomponent fiber. The core layer comprises regular fibers having a denier greater than the fine fibers of the core layer and in an amount to provide flexural rigidity to the laminate.

[0010] The binder fibers preferably have a denier in the range of 0.8-200, with a preferred range of 3-25 denier. The core layer batt has a basis weight in the range of 6-24 ounces/yd<sup>2</sup>, with a preferred range of 6-12 ounces/yd<sup>2</sup>. The core layer batt has a thickness of 0.5-2.0 inches, with a preferred thickness of 0.5-1.0 inches.

[0011] The laminate can further include first and second web adhesive layers that are positioned between each of the outer layers and the core layer. The web adhesive layers enhance the bonding between the outer layers and the core layer. Preferably, the web adhesive layer is a sheet of nonwoven polyester fibers.

[0012] The outer layers preferably comprise 50-100% by weight of thermoplastic fibers with a denier of 0.8-200 and 0-50% by weight of binder materials. The binder materials can include binder fibers. Additionally, the binder materials can include a thermosetting resin, which is preferably a thermosetting powder that is present in an amount up to 20% by weight of the outer layers.

[0013] The strengthening layers are preferably thinner than the core layer. The core layer has a greater resistivity than the strengthening layers. Preferably, each strengthening layer comprises less than 20% fine fibers and the core layer comprises at least 25% fine fibers. The percentage of fine fibers in each of the strengthening layers is preferably not greater than half the percentage of fine fibers in the core layer and the fine fibers of each strengthening layer not exceeding 20%.

[0014] Headliners made according to the invention have better sound absorbing properties and yet maintain the required structural rigidity properties, while minimizing thickness and density to maximize vehicle headroom and fuel efficiency, and are recyclable. Further, the headliners according to the invention are free of fiberglass and are flexible enough to avoid failure during installation and

are less irritable to workers during handling, while satisfying requirements for low density and dimensional stability.

[0015] In yet another embodiment, the invention relates to a laminate comprising first and second strengthening layers and an intermediate core layer. Each of the strengthening layers comprises a batt of nonwoven polymeric fibers. The strengthening layers provide flexural rigidity for the laminate. The core layer provides sound absorption for the laminate and includes a batt of nonwoven thermoplastic fibers. The core layer batt preferably comprises 20-50% fine fibers with a denier in the range of 0.8-3.0, 10-50% binder fibers and the balance regular fibers with a denier in the range of 4.0-15.0, and . The first and second strengthening layers each comprise a batt of nonwoven polymeric fibers and have a density greater than the core layer.

[0016] The strengthening layers are preferably thinner than the core layer. The core layer has a greater resistivity than the strengthening layers. Preferably, each strengthening layer comprises less than 20% fine fibers and the core layer comprises at least 25% fine fibers. The percentage of fine fibers in each of the strengthening layers is preferably not greater than half the percentage of fine fibers in the core layer and the fine fibers of each strengthening layer not exceeding 20%.

[0017] In another embodiment, the invention relates to a laminate comprising first and second strengthening layers and an intermediate core layer. Each of the strengthening layers comprises a batt of nonwoven polymeric fibers. The strengthening layers provide the predominate flexural rigidity for the laminate. The laminate further comprises a core layer disposed between the strengthening layers. The core layer provides sound absorption for the laminate. The core layer includes a batt of nonwoven thermoplastic fibers. The core layer batt preferably comprises 20-50% fine fibers with a denier in the range of 0.8-3.0, 10-50% binder fibers, and the balance regular fibers with a denier in the range of 4.0-15.0. The first and second strengthening layers each comprise a batt of nonwoven polymeric fibers and the core layer has a resistivity greater than at least one of the first and second

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strengthening layers.

## Brief Description of Drawings

- [0018] The invention will now be described with reference to the drawings in which:
- [0019] FIG. 1 illustrates a vehicle headliner according to the invention; and
- [0020] FIG. 2 is a cross-section taken along the lines 2-2 of FIG. 1 illustrating the laminate construction of the vehicle headliner according to the invention.

## Detailed Description

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- [0021] -6-FIG. 1 illustrates a headliner 10 according to the invention. The headliner 10 has improved sound absorbing properties in combination with structural rigidity, while maintaining a relatively thin cross-section. The headliner 10 accomplishes the sound absorbing function while maintaining sufficient structural rigidity to avoid bowing or sagging when exposed to heat and is capable of supporting at least its own weight. The headliner 10 accomplishes this result without undue thickness, which would undesirably reduce the available headroom in the passenger compartment of the vehicle and without undue density which would decrease vehicle fuel efficiency.

- [0022] As best seen in FIG. 2, the headliner 10 comprises a laminate construction including a core layer 12 sandwiched between two stiffening layers 14 and 16. A decorative cover 18 is applied to the stiffening layer (in this case stiffening layer 16) that faces the interior of the vehicle. The decorative fabric covering 18 defines the ceiling of the passenger compartment when the headliner is installed. Preferably, layers of web adhesive 20, 22 are disposed between each stiffening layer 14, 16 and the core layer 12 to enhance the bond therebetween.

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- [0023] The core layer 12 comprises a batt of a blend of nonwoven fibers, including fine denier fibers, regular denier fibers, and binder materials, which preferably includes binder fibers with a lower melting point fiber component. The denier of the fibers in the core layer can vary over a wide range but generally will be in the range of 0.8 to 200, denier, and preferably in the range of 0.8 to 15 denier.

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Preferably the core layer contains 20-50% by weight (all composition percentages are by weight unless otherwise noted) of fine fibers in the range of approximately 0.8 to 3 denier, 0 of fibers in the range of approximately 4 to 15 denier, and 10-50% binder fibers. At least some of the binder fibers can be the fine denier fibers and the regular denier fibers, especially if either of these fibers is a bicomponent fiber having a high melting point core and a low melting point sheath, such as is found in U.S. Patent No. 4,195,112 to Sheard. The binder fibers can also be a blend of high and low melting point thermoplastic fibers.

[0024] The core layer batt fiber blend with the fine denier fibers has excellent sound absorption properties while maintaining a low mass. The thickness of the core layer ranges from 0.5 to 2", and is preferably from 0.5 to 1". The basis weight of the core layer 12 can range from 6 to 24 ounces/yd<sup>2</sup> and is preferably in the range of 6 to 12 ounces/yd<sup>2</sup>. The fibers in the core layer can be a variety of synthetic and natural fiber and are preferably thermoplastic fibers, including polyester, polypropylene, nylon, and copolymeric bicomponent fiber of polyester.

[0025] The binder fibers can be mixed with the fine and regular denier fibers to provide the core layer 12 with dimensional stability when exposed to high and/or low temperatures, humidity, or mechanical strain. Preferably the binder fibers are fully or partially crystallized bicomponent or staple fibers, such as Hoechst J58, Wellman T0196, or Unitika 7080 polyester or polyolefin bicomponent fibers. The bicomponent fibers are formed a low melting point sheath in combination with a high melting point core construction. The low melting point material will soften and bond with other fibers in the core layer 12 to bond the core layer fibers at their cross over points, leaving open the interstitial spaces between the fibers, permitting the sound waves to pass into the core for absorption.

[0026] The stiffening layers 14 and 16 can comprise a batt of similar or dissimilar fiber blends of nonwoven fibers having a denier in the range of 0.8 to 200, and preferably in the range of 3 to 25 denier. The stiffening layers 14 and 16 are generally from 0.1 to 1.0" thick, preferably are from 0.2 to 0.5" thick, and contain 20-50% binder material. The binder material can include binder fibers as well as

other materials, such as resins. The stiffening layers have a basis weight in the range of 3 to 24 ounces/yd<sup>2</sup>, and preferably in the range from 6 to 18 ounces/yd<sup>2</sup>.

[0027] The fibers comprising the stiffening layers 14 and 16 are preferably any thermoplastic plastic fiber, such as polyester, polypropylene, nylon, and copolymer bicomponent fiber of polyester. In essence, the fibers of the stiffening layers 14, 16 can be the same fibers as the core, but preferably do not include the fine fibers because of their relative reduced strength characteristic. But, fine fibers can be included in the stiffening layers as long as the necessary strength is achieved.

[0028] Although it is not preferred, it is within the scope of the invention for the stiffening layers to include thermosetting resins but care must be taken to make sure the resin does not block the interstitial spaces between the fibers to a degree that the beneficial sound absorbing properties of the laminate are lost. The clogging of the interstitial spaces increases the batts sound reflection characteristics which prevents the sound waves from entering the core where they can be absorbed. Preferably, a thermosetting powder is used instead of a liquid resin. The thermosetting powder can be applied to the fibers without clogging the interstitial spaces between the fibers as much as a liquid thermosetting resin that is sprayed onto the fibers. The thermosetting binder can include phenolic, epoxy, or urethane binders, for example. If a thermosetting binder material is used, it is preferred that it does not comprise more than 20% of the strengthening layer.

[0029] The decorative fabric covering 18 can be made of any suitable fabric conventionally used for headliners and is not a part of the invention. Also, depending on the characteristics of the stiffening layer 16, it is possible to forego the decorative fabric covering 18 if the characteristics of the stiffening layer 16 are aesthetically satisfactory. The decorative covering material 18 preferably comprises urethane foam-backed knit fabrics, or needle punched fabrics.

[0030] The web adhesive layers 20, 22 are preferably a sheet of nonwoven thermoplastic fibers having interstitial spaces between the fibers. The fibers are preferably co-polyester. The web adhesive is advantageous or the prior techniques,



such as a liquid adhesive or liquid resin, for bonding together the laminate layers because the web adhesive does not fill in the interstitial spaces between the fibers at the interface between the laminate layers but forms a fiber to fiber bond, thereby increasing the bond without substantially decreasing the sound reflectance of the laminate. A suitable web adhesive is PE2900 manufactured by Spunfab, Ltd. Of Cuyahoga Falls, OH.

[0031] In a preferred embodiment, the core layer 12 has a fiber composition of 40% 0.9 denier 1 1/2 inch polyethylene terephthalate (PET) fibers, 35% 4 denier 2 inch PET bicomponent fibers, and 25% 15 denier 2 inch PET fibers. The core layer has a nominal thickness of approximately 1-inch and a basis weight of 12 oz/yd<sup>2</sup>. Each of the stiffening layers has a fiber composition of 40% 4 denier 2 inch PET heat resistant sheath core bicomponent fibers and 60% 15 denier 2 inch PET fibers. The stiffening layers have a nominal thickness of 0.30 inches and a basis weight of 12 oz/yd<sup>2</sup>. The web adhesive layer is a thermoplastic PET web adhesive (Spunfab PE2900).

[0032] The headliner 10 is preferably manufactured by simultaneously thermoforming the core layer 12, stiffening layers 14 and 16, and the decorative fabric covering 18 and web adhesive layers 20, 22 if used. The thermoforming can include preheating of the materials using radiant, conductive or convective sources followed by molding in cold tools, or by molding in thermally regulated warm or hot tools.

[0033] During molding of the headliner, the mold is closed and cooled to a temperature less than the melting point of the binder materials to thereby set the thermoplastic binder materials and form the fiber to fiber bonds at the fiber cross over points. Alternatively, cool laminate may be presented to a thermally regulated warm or hot tool to thereby soften the binder materials and form the fiber to fiber bonds. The laminate is compressed (either before or after the softening of the binder material) to form the desired contoured surface of the headliner and, in many cases, structural ribs in headliner. The amount of heating and compression will depend on the materials used in the laminate and the desired properties of the final headliner. After heating and compression, the general overall thickness of the

headliner is about 20 mm and the structural ribs have a thickness of about 2 mm.

[0034] If no web adhesive or other adhesive is used between the layers, the layers can be self-bonded together under the influence of heat pressure of the molding operation which causes at the interface between the layers to bond at the fiber cross over points. If the decorative fabric covering 18 is used, it can be molded to a previously formed substrate of the core layer 12 and stiffening layers 14 and 16 as a secondary step. Advantageously, the materials can be molded to variable thickness to accommodate design requirements within a range of 0.1 to 1.5" thick.

[0035] The advantages of the headliner 10 according to the invention are best seen by reviewing various molded samples of laminates according to the invention and compared against prior headliner constructions.

[0036]

Table 1 illustrates the increased modulus of elasticity obtained from the I-beam construction as compared to a single layer construction for various laminate thicknesses. Sample 1 is a construction according to the invention. It has an overall basis weight of 24 ounces/yd<sup>2</sup>. The core layer has a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 25% Wellman 15 denier PET staple fibers (Wellman 15), 25% Wellman 6 denier PET staple fibers (Wellman 6), and 50% Unitika 4 denier PET sheath-core bicomponent type 7080 fibers (Unitika 4). The first and second stiffening layers both have a basis weight of 6 ounces/yd<sup>2</sup> and comprise a fiber blend of 50% Wellman 6 and 50% Unitika 4. The single layer construction (Single Layer 1) has an overall basis weight of 24 ounces/yd<sup>2</sup> and comprises a blend of fibers identical to the core layer of Sample 1. The Sample 1 and Single Layer 1 laminates were made by first pre-heating each laminate for 2-3 minutes by exposing the top and bottom of each laminate with an infrared heating element having a surface temperature of 650° - 850° F. The pre-heated laminates were then placed in a flat mold under 1-2 psi where they cooled for approximately one minute. All of the laminates subsequently described herein were made in the same manner. Table 1 shows the modulus of elasticity according to ASTM D790 for Sample 1 and Single Layer 1, each having identical basis weight and thickness. From table 1 it can be seen that the I-beam construction of Sample 1 provides

increased modulus of elasticity when compared to Single Layer 1 for a given thickness.

[0037] *Table 1: Comparison of Modulus of Elasticity between laminate Construction and a single layer Construction at required Thickness*

[t7]

Sample	Thickness (inches)	Modulus of Elasticity (psi; ASTM D790)
Sample 1	.12	16,800
Single Layer 1	.12	14,500
Sample 1	.45	1,700
Single Layer 1	.45	1,000
Sample 1	.68	680
Single Layer 1	.68	205

[0038] Table 2 illustrates the sound absorption benefits per ASTM C423 testing of the core layer 12 comprised of a fiber blend including fine denier fibers (Sample 2) as compared to a currently manufactured standard substrate (Standard Substrate) which do not have a fiber blend that includes fine denier fibers.

[0039] Sample 2 is only a core layer 12 having a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 20% Wellman 15, 10% Wellman 4.75 denier PET sheath-core bicomponent type 712P fibers (Wellman 4.75), and 70% Wellman 1.2 denier PET staple fibers (Wellman 1.2).

[0040] The Standard Substrate weighs 18 ounces/yd<sup>2</sup> and has a fiber blend of 15% Wellman 4.75, and 85% Talon 6 denier mixed reclaimed synthetic fibers (Talon 6). Sample 2 has a thickness of 0.94" and the Standard Substrate has a thickness of 0.95 inches.

[0041] *Table 2: Comparison of Sound Absorption Properties Between a Core Layer with Fine Denier Fibers and a Heavier Standard Substrate at an equal Thickness*

[t1]

Sample	Percent Sound Absorption at Various Frequencies				
	250HZ	500HZ	1000 HZ	2000 HZ	4000 HZ
Sample 2	26	52	73	81	88
Standard Substrate	22	48	72	93	91

[0042] From table 2 it can be seen that even though Sample 2 with the fine fibers has a two-thirds the mass to absorb sound it still absorbs a similar percentage of sound over the tested range to that of the Standard Substrate, and has a slightly better performance at the lower frequencies and slightly worse performance at the higher frequencies. Therefore, the core layer according to the invention, as illustrated by Sample 2, provides generally better sound absorption in the lower frequency range for a given thickness, but at a reduced weight. The reduced weight places less load on the headliner and helps to reduce the vehicle weight, which are advance over prior headliner constructions.

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[0043] Table 3 illustrates the ASTM C423 sound absorbing properties of a laminate with I-beam construction comprising the core layer 12 and the stiffening layers 14 and 16 (Sample 3) as compared to a single layer (Single Layer 2) of sound absorbing material at a given basis weight and thickness. Sample 3 comprises a core layer weighing 12 ounces/yd<sup>2</sup> with a fiber blend of 50% Wellman 6, 35% Wellman 0.9 denier PET staple fibers (Wellman 0.9), and 15% Wellman 4.75. Sample 3 also includes stiffening layers 14 and 16 weighing 12 ounces/yd<sup>2</sup> and comprised of 20% Wellman 15, 50% Wellman 6, and 30% Unitika 4. Single Layer 2 is actually three layers of the same material. Each layer weighs 12 ounces/yd<sup>2</sup> with a fiber blend of 100% Talon 6 denier mixed reclaimed synthetic fibers (Talon 6). The Talon 6 material has denier in the range of 3-15 denier. The average denier is 6. The overall basis weight is of Single Layer 2 is 36 ounces/yd<sup>2</sup>.

[0044] Sample 3 and Single Layer 2 both have a basis weight of 36 ounces/yd<sup>2</sup> and are similar in thickness with Sample 3 having a thickness of 0.47" and the single layer having a thickness of 0.50". As can be seen from table 3, the laminate of Sample 3 according to the invention has significantly better sound absorbing properties throughout the entire tested range. Therefore, for a given weight and thickness, a laminate made according to the invention provides significantly better sound absorbing properties than previous single layer constructions.

[0045]

*Table 3: Comparison of Sound Absorption Properties Between a Laminate Construction and a Single Layer at equal Basis and Generally equal Thickness*

[t2]

Sample	Percent Sound Absorption at Various Frequencies				
	250 HZ	500 HZ	1000 HZ	2000 HZ	4000 HZ
Sample 3	9	28	55	78	89
Single Layer 2	7	15	40	59	83

[0046] Table 4 illustrates the structural rigidity of previous laminate constructions and laminate constructions according to the invention by comparing the sag of the materials at approximately equal thicknesses with varying basis weights and binder material percentages.

[0047] The cantilevered beam sag test consisted of taking a 3" x 12" section from each flat molded sample and clamping the first two inches of the 12" length. The cantilevered beam was exposed to 185 ° F for 24 hours under its own weight. The amount of sag was measured by the deflection of the extreme end of the cantilever beam sample.

[0048] Samples 4, 9 and 14 according to the invention all comprise a core layer 12 having a fiber blend of 30% Wellman 15, 45% Wellman 0.9, and 25% Unitika 4, and a basis weight of 12 ounces/yd<sup>2</sup>. Additionally, the stiffening layers 14 and 16 have a basis weight of 12 ounces/yd<sup>2</sup> and are a blend of 50% Wellman 15 and 50% Wellman 4.75. Overall, the core layer 12 comprises 8% heat resistant thermoplastic binder material.

[0049] Samples 5, 10, and 15 have an overall basis weight of 36 ounces/yd<sup>2</sup>. The core layer 12 has a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 30% Wellman 6, 45% Wellman 0.9 and 25% Unitika 4. The stiffening layers 14 and 16 each have a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 50% Wellman 15, 25% Unitika 4 and 25% polyester spunbond scrim. Overall, the core layer 12 comprises 25% heat resistant thermoplastic binder material.

[0050] Samples 6, 11, and 16 have an overall basis weight of 36 ounces/yd<sup>2</sup> and an overall composition comprising 33% heat resistant thermoplastic binder material. The core layer 12 has a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 67% Martin-Color-Fl 200 denier PET staple (Martin) and 33% BF Goodrich polyvinyl latex type 352 (BF Goodrich). The stiffening layers 14 and 16 each have a basis weight of

12 ounces/yd<sup>2</sup> and a fiber blend of 50% Wellman 15 and 50% Unitika 4.

[0051] *Table 4: Comparison of Laminate Sag with and without Binder Fibers at Approximately equal Thickness*

[t3]

Sample	Basis Weight (oz/yd <sup>2</sup> )	Thickness (inches)	Heat Resistant Thermoplastic Binder % (Percentage)	Sag (inches)
Prior 1	52	.18	0	.35
Sample 4	36	.18	8	3.94
Sample 5	36	.20	25	2.8
Sample 6	36	.19	33	1.65
Sample 7	36	.20	42	1.14
Sample 8	36	.12	50	.59

[t4]

Sample	Basis Weight (oz/yd <sup>2</sup> )	Thickness (inches)	Heat Resistant Thermoplastic Binder % (Percentage)	Sag (inches)
Prior 2	52	.49	0	1.85
Sample 9	36	.38	8	3.46
Sample 10	36	.46	25	3.11
Sample 11	36	.44	33	1.46
Sample 12	36	.46	42	1.42
Sample 13	36	.47	50	.67

Sample	Basis Weight (oz/yd <sup>2</sup> )	Thickness (inches)	Heat Resistant Thermoplastic Binder % (Percentage)	Sag (inches)
Prior 3	38	.82	0	1.97
Sample 14	36	.57	8	3.51
Sample 15	36	.62	25	2.71
Sample 16	36	.60	33	1.69
Sample 17	36	.59	42	1.57
Sample 18	36	.68	50	0.39

[0052]

Samples 7, 12, and 17 have an overall basis weight of 36 ounces/yd<sup>2</sup> and an overall composition of 42% heat resistant thermoplastic binder material. The core layer 12 has a basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 30% Wellman 6, 45% Wellman 0.9, and 25% Unitika 4. The stiffening layers 14 and 16 each have an

overall basis weight of 12 ounces/yd<sup>2</sup> and a fiber blend of 50% Wellman 15 and 50% Unitika 4.

[0053] Samples 8, 13, and 18 all have an overall basis weight of 36 ounces/yd<sup>2</sup> and an overall composition of 50% heat resistant thermoplastic binder material. The core layer 12 has a basis weight of 24 ounces/yd<sup>2</sup> and a fiber blend of 25% Wellman 6, 25% Wellman 15, and 50% Unitika 4. The stiffening layers 14 and 16 each have an overall basis weight of 6 ounces/yd<sup>2</sup> and a fiber blend of 50% Wellman 6 and 50% Unitika 4.

[0054] Table 4 includes three known previous laminate constructions identified as Prior 1, Prior 2, and Prior 3. Prior 1 and Prior 2 have an overall basis weight of 52 ounces/yd<sup>2</sup> and an overall composition that does not include a heat resistant thermoplastic binder. The core layer of Prior 1 and 2 has a basis weight of 20 ounces/yd<sup>2</sup> and a fiber blend of 80% Martin 3 denier and 20% Wellman 4.75. The stiffening layers of Prior 1 and Prior 2 each have a basis weight of 16 ounces/yd<sup>2</sup> and a fiber blend of 65% chopped fiberglass roving, 28% phenol-formaldehyde thermoset binder, 4% polyester spunbound scrim, and 3% polyethylene film.

[0055] Prior 3 has an overall basis weight of 38 ounces/yd<sup>2</sup> and an overall composition that does not include any heat resistant thermoplastic binder material. The core layer for Prior 3 has a basis weight of 16 ounces/yd<sup>2</sup> and a fiber blend of 44% Wellman 15 and 56% BF Goodrich. The stiffening layers of Prior 3 each have a basis weight of 11 ounces/yd<sup>2</sup> and a fiber blend of 54% chopped fiberglass roving, 38% phenol-formaldehyde thermoset binder, 5% polyester spunbond scrim, and 3% polyethylene film.

[0056] Table 4 compares the sag properties of these various known laminate constructions and laminate constructions according to the invention. Table 4 shows that for a given thickness, an increase in the heat resistant thermoplastic binder percentage will result in a decrease in the sag as tested. In other words, for a given thickness, as the binder material percentages increase, the laminate better resists sagging. Table 4 also shows that increased basis weight also provides increased resistance to sagging. As seen in table 4, one advantage of the invention

is that for approximately equal basis weights, a laminate made according to the invention has significantly better sag resistance at a thickness less than previous laminate constructions. The ability of the invention to provide superior sag resistance at an equal basis weight but at a reduced thickness is advantageous over prior laminate constructions in that no structural rigidity is sacrificed but increased headroom is gained.

[0057] Table 5 illustrates the relative sound absorption characteristics of a composite laminate made according to the invention as compared to the sound absorption characteristics of the individual layers forming the composite. The laminate used in Table 5 has an overall thickness of 0.65 inches with a basis weight of 24 oz/yd<sup>2</sup>. The laminate comprises a core layer sandwiched between outer layers. The fiber composition of the core layer comprises: 35% of 0.9 denier fibers, 25% of 3 denier fibers, and 40% of 15 denier fibers; resulting in a basis weight of 12 oz/yd<sup>2</sup> and a thickness of 0.35 inches. The fiber composition of each outer layer comprises: 50 % of 3 denier fibers and 50% of 15 denier fibers; resulting in a basis weight of 6 oz/yd<sup>2</sup> and a thickness of 0.15 inches.

[0058] *Table 5: Comparison of Sound Absorption Between the Composite of the Invention and the Individual Layers.*

[t5]

Layer	Weight (oz/yd <sup>2</sup> )	Thickness (inch)	ASTM C423 Reverberation Room Sound Absorption in %				
			250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Composite	24	0.65	22	54	80	90	90
Outer	6	0.15	2	7	13	18	32
Core	12	0.35	4	12	31	54	73
Outer	6	0.15	2	7	13	18	32

[0059] The core layer alone absorbs a much greater percentage of sound at all frequencies than the outer layers. In most cases, the core layer absorbs at least twice as much as the outer layers. The superior sound absorbing characteristics of the core layer over the outer layers is believed to be attributable to the use of the fine denier fibers in the core layer and the greater thickness of the core layer.

[0060] The composite has superior sound absorbing characteristics over all of the



individual layers. The improved sound absorbing characteristics are believed to be mainly related to the increased thickness of the composite as compared to the individual layers.

[0061] The comparison of the sound absorbing characteristics between the composite and the individual layers highlights two guiding principles regarding sound absorption: the finer the fiber size, the better the sound absorbing characteristics, and the thicker the layer, the better the sound absorbing characteristics. These are general characteristics which do not hold under all situations.

[0062] The sound absorption property of a material is a direct function of resistivity, which is itself a function of the thickness of the layer and the total fiber surface area of the layer. In general, sound absorption increases as the resistivity increases--at least up to a point. The total fiber surface area is related to the relative proportion of fiber sizes in a given layer. All things being equal, the smaller the fiber size, the greater the total fiber surface area. Since most layers contain a mixture of different size fibers, the greater the percentage of fine fiber will generally yield greater sound absorption.

[0063] There is a point where the material is so resistant to the passage of sound waves that more sound is reflected than absorbed in response to further increases in the thickness or total fiber surface area. To understand this consequence, the resistivity can be thought of as increasing the average distance that a sound wave must traverse to pass through the layer. Both the thickness and total fiber surface area impact the average distance. The thinner the layer, the shorter will be the average distance through the layer. The greater the total fiber surface area, the more a particular sound wave will have to reflect from fiber to fiber to pass through the layer since it is less likely that a direct path exists. As the total fiber surface area increases, generally so does the number of fibers. At some point, the increased number of fibers will eliminate most of the interstitial spaces between the fibers and reduce or eliminate paths through the layer. At such time, the layer reflects more sound than is absorbed, reducing the sound absorption characteristics.

[0064] Another way to think of the effect of the increasing total fiber surface area is that in most cases it generally results in an increase of the density for the layer. At some point, the density will be great enough that the layer starts behaving more like a solid and starts reflecting sound.

[0065] While increasing the density of the layer ultimately negatively impacts sound absorption, in general, increasing the density will increase the stiffness or bending resistance of the layer, which helps to prevent sag. As shown in Table 4, in general, stiffness or bending resistance increases as the percentage of binder fiber increases. Generally, most binder fibers are not fine denier. Thus, increased rigidity, whether obtained by greater density, increased binder fibers, or both, can compromise the sound absorbing characteristics of the layer.

[0066] The laminate according to the invention applies these principals in a unique structure to obtain a laminate that is relatively lightweight and then, but still has the desired sound absorbing characteristics and strength required for a headliner. The invention uses an I-beam configuration having a generally three-layer structure. The outer layers are flexurally stiffer than the core layer, even though the core layer is generally thicker than the outer layers. The greater stiffness of the outer layers is attributable to their greater density and/or their greater percentage of binder fibers.

[0067] The relatively thin and stiff outer layers connected by the core layer forms a cross section that better resists bending than a laminate made solely from outer layer material or the core layer material, much like an I-beam or a box-beam construction.

[0068] The core layer, however, has better sound absorbing characteristics than the outer layers, which is attributable to the use of fine denier fibers and/or greater thickness. The selection of materials for the outer layers cannot ignore the sound absorbing properties since the sound must pass through as least one of the outer layers to reach the core layer.

[0069]

It is within the scope of the invention for the core and outer layers to contain

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the same type of fibers, but not to the detriment of the respective predominate functions provided by the core layer and the outer layers. Care must be taken to make sure that the fiber mix, i.e. the percentage of each type of fiber in the layer, in either the core and outer layers does not impair the primary sound absorbing function of the core layer or the primary strength function of the outer layer.

- [0070] The laminate according to the invention maintains the necessary balance between overall laminate thickness, sound absorption performance, and flexural stiffness by selecting the fiber mix such that the outer layers are generally more dense than the core layer and/or the core layer has a greater resistivity than the outer layers.
- [0071] More specifically, it is preferred that the core layer include at least 25 % of fine fibers in order that the laminate have suitable sound absorbing characteristics. The outer layers should not include more than 20% fine fibers.
- [0072] The limits on the fiber mix for the core and outer layers is constrained by the functional requirements of each of the layers. A greater percentage of binder fibers leads to greater flexural stiffness, for a given weight and thickness of the laminate, and coarser binder fibers result in greater stiffness. Thus, another way in which to quantify the limits on the fiber mix of the core and outer layers is that to obtain the desired mix of sound absorption and flexural stiffness, the percentage of fine fibers in an outer layer should not be more than half the percentage of fine fibers in the core layer, up to a maximum of 20 % fine fibers in the outer layer.
- [0073] While particular embodiments of the invention have been shown, it will be understood that the invention is not limited thereto since modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. Reasonable variation and modification are possible within the scope of the foregoing disclosure of the invention without departing from the spirit of the invention.

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